4. Sludge Disposal Options

4.1 Sludge Production

In order to quantify the volume of settled solids that could be expected when treating various types of water treatment plant residuals streams, using alum or ferric chloride precipitation techniques, empirical sludge production equations were utilized (Cornwell 1999). The equations used were developed for estimating sludge production from the treatment of raw water for production of drinking water using chemical coagulants. Equation inputs used for this analysis include a volume of residuals treated, the total suspended solids (TSS) concentration in the residuals, and the coagulant dose used for arsenic removal. The coagulant dose range used for precipitation testing was between 25 and 200 mg/L, therefore, sludge production estimates for each coagulant type were calculated using doses of 25, 50, 75, 100, 150, and 200 mg/L. The measured TSS value for each of the residuals used for estimating sludge production along with the actual alum and ferric dose range used for each residuals stream are listed in Table 4-1. SFBW (A) had the highest TSS of 193 mg/L due to the nature of the residuals stream, while the NF (A) concentrate and Ion Ex (B) had TSS concentrations less than 10 mg/L.

The sludge production estimates (dry lb/MG of residuals treated) calculated using the empirical equations for alum and ferric chloride are shown in Figures 4-1 and 4-2, respectively. Both figures show that the SFBW (A) would generate the most sludge per volume of residuals treated. SFBW (A) was generated by backwashing filters that remove larger suspended particles from drinking water, and therefore had a higher TSS concentration than the other residuals analyzed. The RO concentrates, nanofiltration concentrate, and ion exchange regenerant were all generated by treatment processes that were designed for removing dissolved macro molecular or ionic contaminants from drinking water, meaning the TSS concentration in those residuals is low compared to the SFBW.

Figures 4-1 and 4-2 illustrate that ferric chloride generates significantly higher sludge quantities than equivalent doses of alum (on a weight basis). Results from the empirical sludge production calculations demonstrate that the amount of sludge generated using ferric chloride would be 25 to 100 percent higher than the dry weight of the alum sludge produced using similar applied doses. The minimum and maximum amounts of dry sludge per volume of residuals treated for both coagulants are shown in Table 4-2. The sludge production calculation includes the best coagulant dose for arsenic removal for both alum and ferric chloride. The table shows that due to the high doses of ferric chloride necessary for achieving optimal arsenic removal, the sludge amounts produced for the different waste steams would range between 1.0 and 2.0 dry lbs/1,000 gal of residuals treated.

Table 4-1. Parameters used for calculating residuals production estimates

Sample ID	Measured total suspended solids concentration (mg/L)	Alum dose range tested (mg/L)	Ferric chloride dose range tested (mg/L)
SFBW (A)	193.0	25 to 50	25 to 50
RO (A)	32.5	100 to 150	25 to 100
RO (B)	27.5	50 to 100	50 to 100
NF (A)	1.5	75 to 200	75 to 200
Ion Ex (B)	9.0	50 to 200	50 to 200

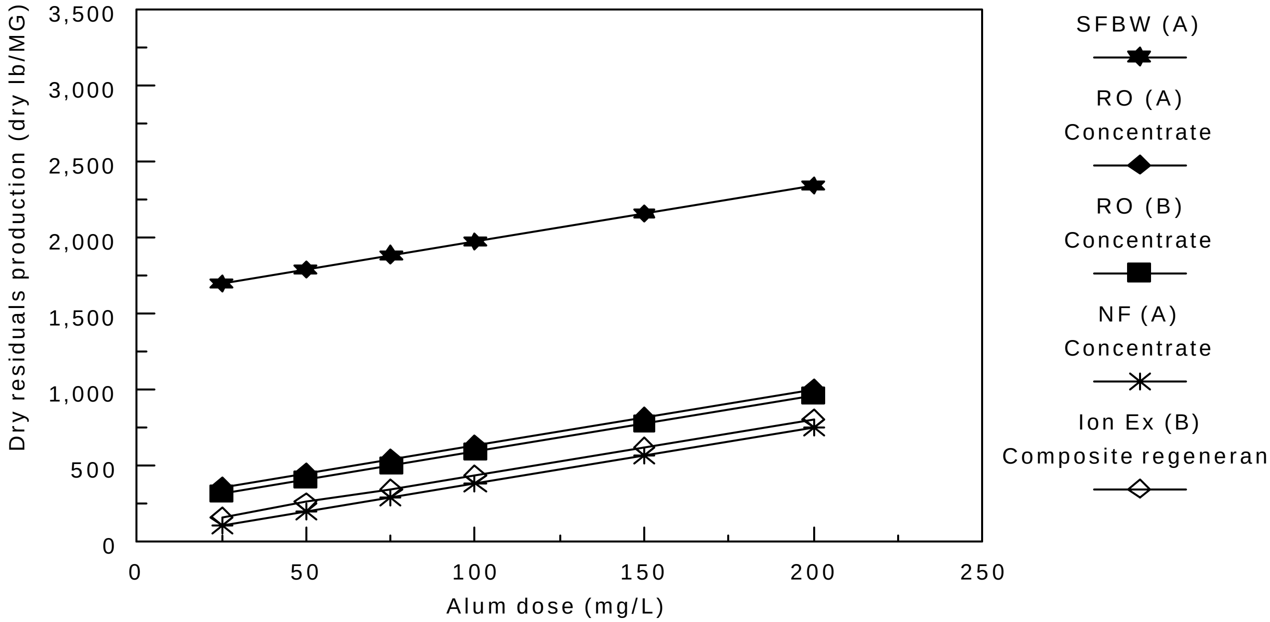

Figure 4-1. Residuals production estimates from alum precipitation of wastewaters containing arsenic

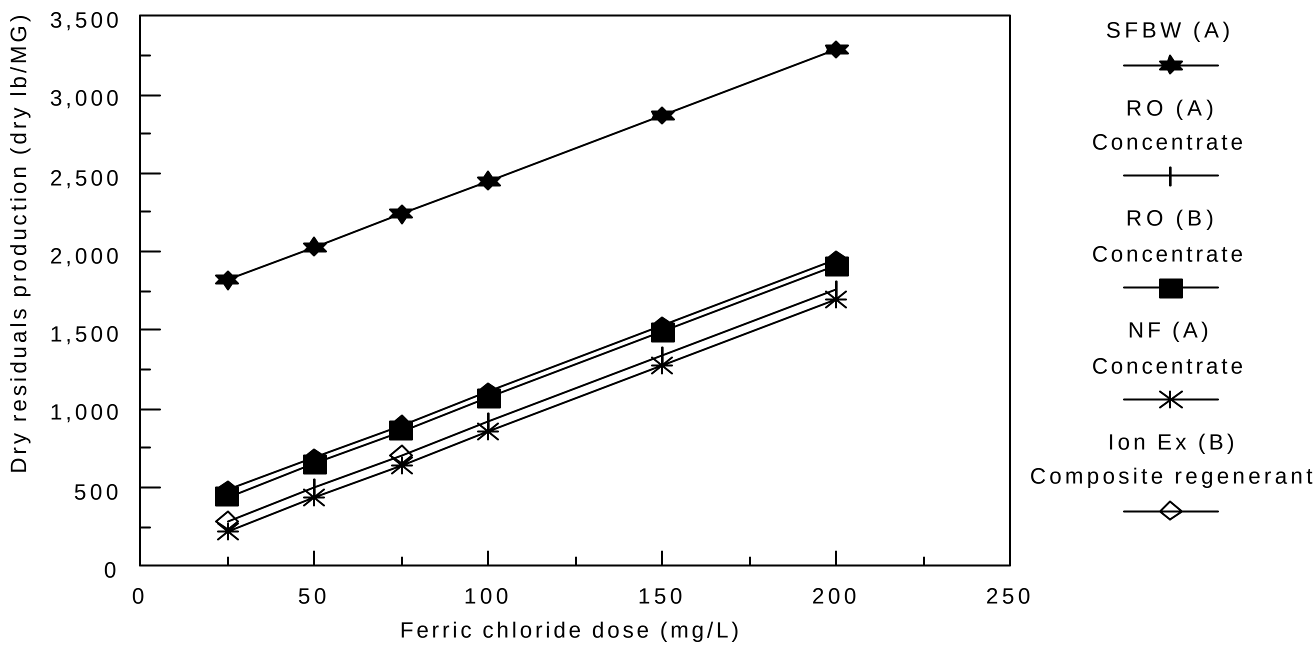

Figure 4-2. Residuals production estimates from ferric chloride precipitation of wastewater containing arsenic

Table 4-2. Estimated sludge production per 1,000 gal of residuals treated by precipitation

Sample ID		Coagulant dose range used for precipitation testing: Alum (mg/L)	Coagulant dose range used for precipitation testing: $FeCl_3$ (mg/L)	Sludge production estimate (dry weight): Alum sludge (lb/1,000 gal)	Sludge production estimate (dry weight): $FeCl_3$ sludge (lb/1,000 gal)
SFBW (A)	min.	25	25	1.70	1.82
	max.	50	50	1.79	2.03
	best dose	–	50	—	2.03
RO (A)	min.	100	25	0.64	0.48
	max.	150	150	0.82	1.53
	best dose	–	150	—	1.53
RO (B)	min.	50	50	0.41	0.65
	max.	100	100	0.60	1.07
	best dose	–	100	—	1.07
NF (A)	min.	75	75	0.29	0.64
	max.	200	200	0.75	1.69
	best dose	150	150	0.56	1.27
Ion Ex (B)	min.	50	50	0.26	0.50
	max.	200	200	0.81	1.75
	best dose	---	---	—	—

--- No optimal condition was found.

4.1.1 Normalizing Sludge Quantities According to Treatment Process Type

The calculated sludge production data (Table 4-2) provide the expected mass of sludge generated per known volume of residuals treated, however, these data do not provide a mass of sludge produced per volume of raw water treated by each of the different treatment processes. Normalizing these results provides a better understanding of how much sludge each treatment process analyzed would be expected to generate. In order to normalize these data, the following assumptions were made:

- Percentage of residuals generated by each treatment process (RO, NF, Fe/Mn removal, Ion Ex)
- Total treatment plant process (raw water) flow rate (in this case 1 mgd was used)

Each of these parameters is defined in Table 4-3.

These data show that the membrane treatment processes would generate a significantly higher volume of residuals than the Fe/Mn filtration and ion exchange systems. Both RO and NF would generate approximately 150,000 gpd per 1 mgd treated, compared to 50,000 gpd for Fe/Mn filtration and 20,000 gpd for ion exchange.

Table 4-3. Estimated volume of residuals generated per 1 MG treated

	Total plant flow rate (mgd)	Residuals generated (percent of total flow)	Volume of residuals generated (gpd)
Reverse osmosis	1	15	150,000
Nanofiltration	1	15	150,000
Fe/Mn filtration	1	5	50,000
Ion exchange	1	2	20,000

In order to determine the mass of sludge produced per 1 mgd of raw water treated, the sludge production amounts (dry lb/1,000 gal) calculated for the best coagulant dose (Table 4-2) was multiplied by the volume of residuals generated for each process (Table 4-3). These data are summarized in Table 4-4.

The table shows that the mass of sludge produced per MG of raw water treated is highest for the membrane processes due to the large volume of residuals generated. For example, the reverse osmosis facility that generated the RO

Table 4-4. Estimated sludge production for a 1-mgd treatment facility

Sample ID	Residuals volume	Best $FeCl_3$ dose* (mg/L)	Sludge production using best $FeCl_3$ dose (dry lb/1,000 gal of wastewater)	Total sludge production (dry lb/mil gal raw water treated)
SFBW (A)	50,000	50	2.03	101.5
RO (A)	150,000	150	1.53	229.5
RO (B)	150,000	150	1.07	160.5
NF (A)	150,000	150	1.27	190.5
Ion Ex (B)	20,000	200	1.75	35

*Best $FeCl_3$ dose found for removing As from each untreated residuals sample during precipitation testing.

(A) residuals would be expected to generate almost 230 dry lbs of sludge per MG treated if removal of arsenic from the concentrate was required. The ion exchange facility (Ion Ex B) would produce the least amount of sludge at 35 dry lb/MG raw water treated.

4.2 Federal Disposal Regulations

There are no existing comprehensive federal regulations that specifically apply to water treatment plant (WTP) residuals. There are, however, existing federal regulations that were developed for biosolids and solid waste disposal. Many states have adopted all or parts of these federal guidelines for regulating WTP residuals disposal.

Federal statutory and regulatory requirements for disposal of liquid and solid WTP residuals were summarized in a recent publication (Science Applications International 2000). A summary description of some of the federal regulations that are currently being adopted by states for applications involving WTP residuals are as follows:

- 40 CFR 257: Classification of Solid Waste Disposal Facilities and Practices
- 40 CFR 258: Criteria for Municipal Solid Waste Landfills (MSWLF)
- 40 CFR 261: Toxicity Characteristic Leaching Procedure (TCLP) Test
- 40 CFR 403: General Pretreatment Regulations for Existing and New Sources of Pollution
- 40 CFR 503: Standards for the Disposal of Sewage Sludge
- CERCLA: Comprehensive Environmental Response Compensation Liability Act
- HMTA: Hazardous Materials Transportation Act

The Clean Water Act (CWA), Section 405, established guidelines for the use and disposal of sewage sludge in order to protect leaching of contaminants into waterways. Leaching of metals into groundwater is the primary issue addressed by CWA Section 405. The framework defined by CWA Section 405 was also adopted for use in land applied WTP sludge. The Resource Conservation and Recovery Act (RCRA) was established primarily to determine toxicity or hazard potential of a solid waste prior to landfilling in order to protect land, water, and air from contamination. The RCRA also provides guidelines concerning the following topics:

- Classification of hazardous wastes
- Standard for treatment, storage, and final use
- Enforcement of standards
- Authorization for states to implement regulations
- Cradle to grave manifest system

Although developed for biosolids and solid waste, specific sections of RCRA have been adopted by many states for regulating WTP residuals end use applications. A summary of the 40 CFR sections that could apply to WTP residuals are listed in the following paragraphs.

4.2.1 40 CFR 257: Criteria for Classification of Solid Waste Disposal Facilities and Practices

This regulation includes provisions that deal with land application of a solid waste, including WTP residuals. In order to comply with Section 405(d) of the Clean Water Act, the owner or generator of a publicly owned treatment facility must comply with the guidelines for sludge applications outlined in 40 CFR 257. The regulation contains specific criteria governing application of sludge to land for production of human food-chain crops and limiting annual and cumulative applications of cadmium and PCBs.

4.2.2 40 CFR 258: Criteria for Municipal Solid Waste Landfills (MSWLF)

The 40 CFR 258 regulation establishes minimum national criteria for all MSWLF units and for MSWLF that are used to dispose of biosolids. Biosolids, solid wastes, and WTP residuals that are placed in a MSWLF must be nonhazardous as determined by 40 CFR 261, and must not contain free liquids as determined by the Paint Filter Liquid Tests.

4.2.3 40 CFR 261: Identification and Listing of Hazardous Wastes

The 40 CFR 261 identifies the solid waste materials which are subject to regulation as a hazardous waste. A solid is considered a hazardous waste if it exhibits any of the characteristics of ignitability, corrosivity, reactivity, or toxicity as defined in Subpart C of CFR 261 or if it is listed in Subpart D of CFR 261. This regulation is pertinent since the final use options considered for WTP residuals application require a nonhazardous designation. Since WTP residuals are not ignitable, corrosive, reactive, or considered hazardous wastes, the toxicity characteristic leaching procedure (TCLP) could be used as the primary indicator that a WTP residual is not a hazardous material. The TCLP regulatory limits established by 40 CFR 261 are listed in Table 4-5.

Table 4-5. EPA 40 CFR Part 261 TCLP limits

Contaminant	EPA Section 40 Part 261 TCLP limits (mg/L)
Metals	
Silver	5
Barium	100
Cadmium	1
Chromium	5
Lead	5
Arsenic	**5**
Selenium	1
Mercury	0.2
Volatiles	
Benzene	0.5
Carbon Tetrachloride	0.5
Chlorobenzene	100
Chloroform	6
1,2-Dichloroethane	0.5
1,1-Dichloroethylene	0.7
Methyl ethyl ketone	200
Tetrachloroethylene	0.07
Trichloroethylene	0.5
Vinyl Chloride	0.2
1,4-Dichlorobenzene	7.5
Semi-Volatiles	
o-cresol	200
m-cresol	200
p-cresol	200
Cresol (total)	200
2,4-Dinitrotoluene	0.13
Hexachlorobenzene	0.13
Hexachlorobutadiene	0.5
Hexachloroethane	3
Nitrobenzene	2
Pentachlorophenol	100
Pyridine	5
2,4,5-Trichlorophenol	400
2,4,6-Trichlorophenol	2
1,4-Dichlorobenzene	7.5
Herbicides/Pesticides	
2,4,-D	10
2,4,5-TP (Silvex)	1
Chlordane	0.03
Endrin	0.02
Heptachlor	0.008
Heptachlor epoxide	0.008
Lindane	0.44
Methoxychlor	10
Toxaphene	0.5

4.2.4 40 CFR 403: General Pretreatment Regulations for Existing and New Sources of Pollution

Discharges to the sanitary sewer are subject to EPA's National Pretreatment Standards and any additional pretreatment requirements mandated by the state or wastewater treatment facility. Examples of arsenic limits from seven states reviewed in a recent USEPA publication (Science Applications International 2000) range from 0.051 mg/L for Albuquerque, New Mexico to 1.07 mg/L for Farmington, New Mexico. Residual arsenic levels in this range were attained through precipitation or adsorption treatments for all wastewaters examined in this work except Ion Ex (B). The requirements imposed on a wastewater treatment facility through a permit and/or local ordinance are necessary to enable the facility to achieve compliance with their NPDES permit.

Pretreatment required prior to discharge liquid residuals into the environment is typically site-specific. Several states have a surface water quality arsenic standard of 0.05 mg/L for waters used as public water supplies (Science Applications International 2000).

4.2.5 40 CFR 503: Standards for the Use or Disposal of Sewage Sludge

This regulation describes comprehensive criteria for the management of biosolids. Under 40 CFR 503, biosolids are either land applied in bulk form, sold, or given away. Application can occur on either agricultural land, forests, public contact sites, and reclamation sites or on lawns and home gardens. In order for biosolids to be land applied, criteria for pollutant limits, pathogens, and vector attraction reduction must be met. The Part 503 pollutant limits for land application are given in Table 4-6. All biosolids that are to be land applied must meet the ceiling concentrations in *Table 1 of 503.13*. Bulk biosolids that are applied to agricultural land, forest, public contract sites, or reclamation sites must also either meet the pollutant limits in *Table 3 of 503.13* or be applied at rates so that the cumulative loading rates in *Table 2 of 503.13* are not exceeded. Bulk biosolids that are applied to lawn or home gardens must meet the pollutant limits in *Table 3 of 503.13*. Biosolids that are sold or given away must either meet the pollutant limits in *Table 3 of 503.13*, or be applied so as not to exceed the annual pollutant rates in *Table 4 of 503.13*, while still meeting the ceiling concentrations in *Table 1 of 503.13*.

4.2.6 Comprehensive Environmental Response Compensation Liability Act (CERCLA)

The CERCLA, also known as the Superfund Act, was established to deal with the numerous existing abandoned or uncontrolled hazardous waste disposal sites that pose a real threat to public health and safety as well as to the environment. Prior to the act's passage, USEPA was only authorized to regulate hazardous waste management at active and properly closed sites. The Superfund, which is essentially a pool of money derived from special taxes, forms the core of CERCLA. Establishment of this fund fulfilled the primary focus of CERCLA. An expansion of the Superfund pool that serves to continue cleanup efforts begun under CERCLA is provided by the Superfund Amendments and Reauthorization Act (SARA) of 1986. The funds thereof are used to remediate contaminated sites in accord with RCRA requirements.

The USEPA is authorized under CERCLA to take necessary short-term actions to deal with sites posing some immediate threat to human health or the environment as well as to implement long-term plans to clean up complex sites, which are selected on the basis of risk assessments. The identification of responsible parties is an important part of the remediation process. Possibly the most noteworthy aspect of these regulations, however, is that they employ a volume use basis in assessing cleanup costs, which could potentially place the liability with a utility whose sludge did not cause the problem.

4.2.7 Hazardous Materials Transportation Act (HMTA)

The Hazardous Materials Transportation Act (HMTA) applies to all beneficial uses requiring transportation of sludge. The WTP sludge must be determined to be non-hazardous by RCRA and HMTA in order to transport the material. The

Table 4-6. Part 503 pollutant limits for sewage sludge land application

	Table 1 of 503.13 Ceiling concentrations (mg/kg)	*Table 2 of 503.13* Cumulative pollutant loading rates (kg/ha)	*Table 3 of 503.13* Pollutant concentrations (mg/kg)	*Table 4 of 503.13* Annual pollutant loading rates (kg/ha/yr)
Arsenic	75	41	41	2.0
Cadmium	85	39	39	1.9
Copper	4,300	1,500	1,500	75
Lead	840	300	300	15
Mercury	57	17	17	0.85
Molybdenum	75			
Nickel	420	420	420	21
Selenium	100	100	100	5.0
Zinc	7,500	2,800	2,800	140

HMTA also outlines U.S. Department of Transportation (USDOT) packaging requirements.

4.3 Residuals Disposal Options

The effective removal of arsenic from WTP liquid residuals streams results in a supernatant or effluent streams that may meet regulatory criteria for reuse, stream discharge, or sewer disposal and a sludge or media waste that contains a concentrated amount of total arsenic. As discussed in the Federal regulatory review, final land disposal of solid residuals is dependent on the TCLP arsenic leaching (mg/L) and total arsenic concentration (mg/kg), as well as other TCLP or non-metal contaminants regulated by EPA.

Although only a limited amount of sludge solids from precipitation tests were TCLP tested to determine arsenic leaching, all samples tested had TCLP arsenic concentrations well below the 5 mg/L limit. The TCLP arsenic concentrations of the adsorption media tested were also significantly lower than the 5 mg/L maximum limit for arsenic. Based on TCLP arsenic results, these waste samples would be considered nonhazardous (unless other contaminants exist that would fail the TCLP analysis).

If a waste material is found to exceed the TCLP arsenic concentration of 5 mg/L, the liquid or solid material would be considered hazardous and would require disposal in hazardous waste handling facilities. If the material is determined to be nonhazardous, the following disposal options may apply for liquid or solid media wastes:

- Liquid/Semi-Liquid Wastes
  - Stream discharge (NPDES permit probably requires solids removal)
  - Sewer disposal to WWTP
  - Land application
  - MSWLF landfilling (requires dewatering)
- Solid Media
  - Land application
  - Landfilling
  - Regeneration/Reuse

Each of these disposal options are summarized in the following sections. It should be noted that landfill disposal, sewer disposal, land application, and stream discharge regulations vary from state to state. Some states have adopted the Federal regulations for these disposal applications, while others have developed their own specific guidelines for disposal.

4.3.1 Liquid or Semi-Liquid Waste Disposal

Stream Discharge

Discharge of WTP residuals to surface water requires a National Pollutant Discharge Elimination System (NPDES) permit. NPDES permit requirements are based on stream flow conditions and provide maximum limits for solids discharge and contaminant loadings. The limits established in the NPDES for specific contaminants are determined by the water quality criteria established for the receiving water, ambient levels of the specific contaminants, the established low flow condition of the receiving water, and the design flow of the proposed discharge from the arsenic treatment process (Chwirka 1999). Table 3-15 shows treatments successful in reducing arsenic levels to 0.05 mg/L or lower, which is the existing in-stream standard in some states. As shown, one or more treatment techniques were able to attain arsenic concentrations of 0.05 mg/L or lower in all residuals except the ion exchange and activated alumina regenerant streams.

Sewer Disposal

The quality of WTP residuals allowable for discharge to the sanitary sewer is dependent on limits imposed by the wastewater treatment plant receiving the liquid waste. Each WWTP has an Industrial Pretreatment Program to prevent unacceptable concentrations of contaminants from entering the WWTP treatment process. Those guidelines protect the operation of the WWTP from inhibition of the biological processes used to treat municipal wastewater, prevent violations of the WWTP NPDES permit, and prevent unacceptable accumulation of contaminants in the WWTP biosolids. The Industrial Pretreatment Program establishes Technically Based Local Limits (TBLL). The TBLL for arsenic will typically be limited by contamination of the wastewater treatment plant biosolids rather than discharge limitations or process inhibitions (Chwirka 1999).

Land Application

Land application of WTP residuals is dependent on the state regulatory guidelines. Some states do not allow land application of WTP residuals. The general criteria for allowing WTP residuals to be land applied are based on the following Federal regulations:

- EPA CFR 40 261 - TCLP Hazardous Determination
- EPA CFR 40 503 - Biosolids Metals Concentrations
- EPA CFR 40 257 - Solid Waste Disposal

If WTP residuals meet the criteria established by these Federal regulations, as well as any state or local regulations, then the material would be allowed for land application. EPA 503 established maximum loading limits for heavy metals including arsenic. A "clean sludge" limit of 41 mg/kg was established by EPA 503 for biosolids disposal. Clean sludge can be land applied with no limitations (Chwirka 1999). A cumulative arsenic loading limit to soils was set by EPA in the Part 503 regulations at 36.6 lbs/acre (41 kg/ha).

Landfill Disposal (MSWLF)
Municipal solid waste landfills have established a set of disposal guidelines that are similar for most landfill agencies. The basic guidelines for disposal include the following:

- No free liquids (pass paint filter test)
- TCLP nonhazardous (EPA CFR 40 Part 261)
- Non-corrosive, non-reactive, non-ignitable (EPA 261)

Liquid or semi-liquid WTP residuals would require mechanical or nonmechanical dewatering prior to acceptance. If the WTP residuals exceeds the TCLP limits established by EPA 40 CFR 261, then the material would have to be disposed of in a hazardous waste landfill.

4.3.2 Solid Media Disposal

Land Application
The same regulatory requirements used for sludge disposal would apply to disposal of adsorption medias. If the material is determined to be nonhazardous (TCLP limits from EPA 40 CFR 261) and meets the EPA 503 metals limits, then land application is an option. The ability of the solid media to blend into the natural soil environment must also be considered prior to land disposal. Iron-based media may provide an iron amendment to soils, however, aluminum-based media and ion exchange resins would most likely not provide a benefit to soils. Also, under reduced pH conditions, Fe(III) could be reduced to Fe(II), and arsenic bound to iron complexes could be released to surrounding soils.

Landfill Disposal
The same criteria discussed for landfilling WTP sludge would apply to disposal of solid adsorption media. TCLP hazard evaluation, no free liquids, and determination of corrosivity, ignitability, and reactivity are each required prior to acceptance. All solid media samples in this work met the current TCLP arsenic limit of 5.0 mg/L.

Recycling/Reuse
It is possible that adsorption media may be regenerated by the manufacturer and reused for similar or different applications. To determine reuse potential for a specific solid adsorption media, the manufacturer of the media should be contacted.